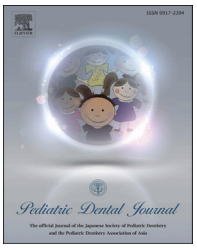
Available online at www.sciencedirect.com

Pediatric Dental Journal

journal homepage: www.elsevier.com/locate/pdj



Review

Silver Diamine Fluoride: Extending the spectrum of Preventive Dentistry, a literature review

Inshiya Alazhar Contractor[*], *Girish M.S.*, *Indira M.D.*

Department of Paediatric and Preventive Dentistry, JSS Dental College and Hospital, JSS Academy of Higeher Education and Research, Mysuru, Karnataka, 570015, India

ARTICLE INFO

Article history:
Received 16 October 2020
Received in revised form
26 November 2020
Accepted 10 December 2020
Available online 10 February 2021

Keywords:
Caries arrest
Caries prevention
Clinical recommendations
Silver diamine fluoride

ABSTRACT

Dental caries continues to be a severe oral health problem despite a decrease in its prevalence over the past few decades. The contemporary philosophy of caries management has shifted from the traditional approach to a newer medical one, that frequently includes utilization of fluoridated and antimicrobial agents. Among these different agents, Silver Diamine Fluoride (SDF)[*] has gained significant recognition. Dr Nishino and Dr Yamaga in Japan, pioneered its application to arrest caries. It is an alkaline, colourless solution composed of diamine-silver and fluoride ions having silver's antibacterial and fluoride's remineralising property. It has been used successfully to arrest and prevent caries in deciduous and permanent teeth, prevent recurrence of secondary caries and treat dentinal hypersensitivity. No adverse systemic effects due to SDF have been noted although black discolouration following its application has raised concerns. When used wisely it is an effective, sustainable and inexpensive option for children with high caries risk, for individuals who cannot endure conventional modalities of restorative treatment and those with special health-care needs. The current review is an insight into the clinical significance and application of SDF based on published literature.

1. Introduction

Dental caries is an irreversible, localised phenomenon that causes chemical dissolution of teeth by the acidic by-products of the biofilm's metabolic processes which covers the affected tooth surface [1]. The traditional management of dental caries emphasized on removing the decayed tissue and successive restoration of the cavity as the primary treatment modality. However, mechanical preparation of teeth is a destructive procedure which also results in removal of the natural dental tissues. Thus, the contemporary philosophy of caries management has shifted from this traditional approach to a newer medical one, that frequently includes utilization of fluoridated agents and antimicrobial agents like silver compounds [2]. Among these different agents, Silver Diamine Fluoride (SDF)[*] has gained significant recognition from both dental clinicians and researchers. The current review is a detailed comprehensive description about silver diamine fluoride

* *Corresponding author.*
E-mail addresses: insucontractor@gmail.com (I.A. Contractor), drgirish@gmail.com (G. M.S.).
[*] SDF: Silver Diamine Fluoride, KI: Potassium Iodide.
https://doi.org/10.1016/j.pdj.2020.12.005
0917-2394/

including its mechanism of action, clinical significance, applications and drawbacks based on published literature.

2. Historical background

The application of silver compounds in the field of dentistry dates to China in 659 AD. Since then it has been successfully used as an antimicrobial material. In earlier times the infected and disintegrated dentine were sterilized using Howe's solution or ammoniacal silver nitrate during a restorative treatment [3]. The solution could also penetrate the affected dentine and fill it with silver particles, widening its utilization as an indirect pulp capping agent [4].

For decades it is a known fact that fluoride is effective in the prevention of caries. Fluoride exerts antimicrobial effects on plaque biofilm. Formation of fluorapatite results in early carious remineralisation. So, it was hypothesised that the combined effects of silver and fluoride would simultaneously have the ability of caries arrest and prevention [5].

Dr Nishino and Dr Yamaga in Japan, pioneered the application of ammoniacal silver fluoride to arrest caries [6]. This led to the approval of the first SDF product, "Saforide" (Bee Brand Medico Dental Co, Ltd) [7] which was effective in caries arrest, prevented secondary caries formation and desensitized hypersensitive dentine. In the following years, similar products became available commercially in various parts of the world. Since 2002 [8], numerous clinical trials on SDF's efficacy have established its effectiveness as an agent to arrest caries. The US Food and Drug Administration in the year 2014, certified SDF as a product for desensitization of dentine in adults. The American Academy of Paediatric Dentistry in 2017 published guidelines for the "Use of Silver Diamine Fluoride for Dental Caries Management in Children and Adolescents, Including Those with Special Health Care Needs." [9].

3. Silver diamine fluoride

SDF is an alkaline, clear and colourless solution composed of diamine-silver and fluoride ion that forms a complex with ammonia [10]. It has a combination of silver's antibacterial and fluoride's remineralising property. The concentration of fluoride in SDF is 44,800 ppm, which is the highest amongst all fluoride agents available in dentistry. What makes SDF unique and different from other caries-preventive agents like stannous fluoride and sodium fluoride, is it's ability to stop the carious process and concurrently prevent the formation of new lesions [5]. Also this complex is less oxidizing and more stable than silver fluoride. The stability of this reagent is pivotal to arrest the progression of caries [10].

4. Mechanism of action

SDF's anticariogenic mechanism has direct actions on bacteria and teeth because of silver and fluoride ions.

4.1. *Effect of SDF on microorganisms*

4.1.1. *Silver*

Silver ions are released when SDF comes in contact with water and other biological fluids [11]. These ions have multiple modes of action which target various biological organisms, their subcellular targets and metabolic mechanisms. The mechanisms are as follows:

- **Enzyme inactivation:** Silver ions interacts with the thiol group of various life sustaining enzymes. This leads to their deactivation and blocks the electron transport system in bacteria [11] causing bacterial cell death.
- **Rupture of cell membrane:** Silver ions can interact and bind to bacterial cell membranes causing it to leak and rupture [12].
- **DNA interaction:** Interaction of the bacterial DNA with silver ions results in DNA mutation and the death of the bacteria [13].

All these interactions result in killing of the bacteria and inhibit the formation of biofilm [14]. Therefore, resistance of bacteria against silver is not easily achieved. Also when the bacteria which are killed by the silver ions get mixed with the living ones, the silver gets reactivated and effectively kills the remaining live bacteria. This is known as a zombie effect which is shown by SDF as well.

A study conducted by Knight et al. [15] showed significant amount reduction in *S. mutans* levels, (most important organism associated with the caries initiation) on dentine surfaces that were treated with SDF. Another study that used multispecies cariogenic biofilms which included *S. mutans*, *S. sobrinus*, *L. rhamnosus*, *L. acidophilus* and *A. naeslundii*, also showed reduced colony forming unit counts following SDF treatment [16]. Apart from causing bacterial cell death, silver also gets incorporated into hydroxyapatite crystal structure, forming silver-containing hydroxyapatite [17], which has resulted in reduced bacterial adhesion and tissue cytotoxicity.

4.1.2. *Fluoride*

Fluoride at high concentrations bind to bacterial cellular components and inhibits biofilm formation. Direct inhibition of cellular enzymes and increase in the cell membrane permeability by formation of hydrogen fluoride results in inhibition of plaque metabolism. [18] Non-metalloenzymes like phosphatases can also be inhibited by fluoride, thus leading to reduced acid production in dental plaque. However, this inhibitory effect is short-lasting, and can be negligible in the reduction of caries.

4.2. *Effect of SDF on dentine minerals*

It is a proven fact that SDF reacts with hydroxyapatite crystals of the tooth and forms calcium fluoride and silver phosphate, which might cause the arrested lesion to harden [7]. However, certain studies showed that the concentration of silver phosphate and calcium fluoride dropped significantly following immersion in artificial saliva [19], or disappeared after washing with water [20] thus questioning its role in hardening the carious lesion. Nonetheless, calcium fluoride

formation in the oral cavity is a major reaction product which serves as a fluoride source. Under acidic conditions, like caries attack, it results in gradual formation of fluorohydroxyapatite [21]. As calcium fluoride is adsorbed onto the surface of the teeth rather than being incorporated in it, it is known as loosely bound fluoride.

4.2.1. *Effect of firmly bound fluoride on dentine minerals*

Fluoride reacts with apatite in numerous ways to promote remineralisation i.e, exchange of hydroxyl ions by fluoride ions, apatite dissolution and formation of calcium fluoride and growth of the fluorapatite crystals from supersaturated solutions [22]. It prevents development of caries by decreasing the dissolution of teeth [23]. In acidic conditions, this fluoride substituted hydroxyapatite is more stable in comparison to hydroxyapatite alone. It is known as firmly bound fluoride as fluorine gets incorporated in the crystalline tooth structure [22].

SDF reacts with calcium and phosphate resulting in the formation of fluorohydroxyapatite with different percentages of fluoride that initiates remineralisation. In has been discovered that an increase in the concentration of SDF increases the apatite fluoride content [24]. In-vitro studies demonstrated that the depth of penetration in enamel with SDF was approximately 25 microns, and 2–3 times more amount of fluoride was retained than in case of sodium fluoride or stannous fluoride [19], suggesting a greater effect of SDF on tooth compared to sodium fluoride or stannous fluoride.

A major factor that determines dentine hardness is its mineral content. Dentinal collagen affects toughness of dentine but does not contribute in its overall hardness. The mineral content of dentine limits the penetration of bacterial acid. Its buffering capacity reacts and helps in neutralization of the acid that penetrates the tooth [25]. Application of SDF increases the mineral content owing to the presence of fluoride and thereby increases the microhardness of the arrested carious lesion.

Chu et al. in 2008, measured the microhardness of arrested dentinal caries on primary teeth that received application of 38% SDF every 12 months. The results showed that the outer 25–200 micrometer of carious dentinal surface which was arrested by the application of SDF was harder compared to the active carious lesions. However, beyond the distance of 225 micrometer from the lesion surface, soft dentinal caries and arrested lesion both had similar microhardness. The high fluoride content in SDF made the surface of the lesions hypermineralized [26].

4.3. *Effect of SDF on dentine collagen*

Organic matrix of dentine is destroyed due to the action of bacterial collagenases, matrix metalloproteinases (MMPs) and cysteine cathepsins which break down type I collagen of dentine. These enzymes, can be activated in an acidic environment. Inhibition of their activities can prevent degradation of collagen which will arrest the caries process. It has been proved that 38% SDF solution inhibits the activities of these enzymes [27]. The alkaline property of SDF contributes in neutralizing the acidity therefore inactivates these enzymes. Silver from the SDF solution is a strong inhibitor of cathepsin B and cathepsin K and a moderate inhibitor of MMP-8 and MMP-9. Whereas, fluoride is a strongly inhibits MMP-2, MMP-8, and MMP-9 [28].

Another way in which fluoride can possibly protect the dentine collagen is by promoting remineralisation. The formed apatite crystals in turn protect and cover the dentine collagen. The surface morphology of the arrested carious deciduous teeth treated with SDF in an ex-vivo study, showed a relatively smooth dentinal surface and only a few collagen fibres of dentine were exposed [27].

5. Clinical applications

SDF's efficacy in the management of dental caries is substantiated with numerous studies and systematic reviews. It accomplishes the US Institute of Medicine's six quality aims [29]:

1. Effective-arrests about 80% of lesions.
2. Safe-clinical trials reported no serious adverse events.
3. Efficient-health professionals can apply it with minimal preparation.
4. Timely-application time is 1 min.
5. Patient centered-minimally invasive and painless.
6. Equitable-affordable and a viable treatment option for low income groups.

5.1. *Caries arrest in deciduous dentition*

In pre-school children, the carious attack on the deciduous teeth generally takes an acute course and pose great difficulties in its management. It has been proved time and again that application of SDF solution can arrest the progression of dental caries in them. According to the meta-analysis by Gao in 2016 [30], 81% of primary teeth treated with SDF showed caries arrest when different application protocols were used and followed up from six to thirty months.

Fung MHT et al. in 2018 [31] evaluated the effect of two different concentrations of SDF (12% and 38%) and two different application protocols (once or twice a year) on dentine caries arrest in deciduous teeth. From the arrest rates it was seen that 38% SDF was better than 12% SDF and semi-annual application was better than annual application. The study also analysed the effect of SDF on different areas of the oral cavity. The results showed great arrest rates in lower anterior teeth, and least in the upper posterior teeth.

Another study by Duangthip D et al. in 2018 [32] compared the effect of three SDF solution applications at yearly intervals and three SDF solution or sodium fluoride varnish applications at weekly intervals to arrest caries in deciduous teeth. It was seen that annual application of SDF was significantly more effectual than biweekly applications of sodium fluoride varnish or SDF solution to arrest active lesions.

A younger age group of children between one to three year were selected by Mabangkhru S et al. in 2020 [33] to evaluate and compare the effectiveness of SDF solution with 5%

sodium fluoride varnish applied semi-annually. The results showed only 37.5% caries arrest with SDF and 20% with sodium fluoride varnish. Though SDF was more effective than sodium fluoride varnish but overall effect was not satisfactory. The reason could be that SDF was applied only for 10 s. Also children having milk more than three times a day and children snacking for more than three times a day had less chances of their lesions being arrested.

A systematic review of 17 randomised clinical trials conducted by Gao et al. on caries arrest and remineralization by professionally applied fluoride therapy concluded that though professionally applied fluoride like sodium fluoride is effective in caries prevention and remineralisation of early enamel caries, 38% SDF is superior to sodium fluoride varnish in arresting caries in dentine in children. It was also found to be better to glass ionomer restorations in arresting caries in dentine [34].

Therefore, SDF can significantly arrest caries in deciduous teeth if it is applied annually or semi-annually. Also, anterior teeth have higher chances of caries arrest compared to posterior teeth. Several studies [32,35], have found that caries arrest is comparatively less in teeth with more plaque. Its effectiveness also depends on the lesion size, duration of application and other dietary habits.

5.2. *Caries prevention in deciduous dentition*

SDF is effective not only in arresting caries but also helps to prevent the development of new lesions. Application of SDF only to carious lesions, has also shown impressive preventive results on other tooth surfaces.

Llodra et al. in 2006 [36] conducted a trial on deciduous and permanent molars and found the development of new carious lesion significantly low in the SDF group compared to the water group. Chu et al. in 2002 [8] found the average number of new lesions in maxillary anterior teeth significantly less in the SDF group compared to fluoride varnish and water group in pre-school children. Based on these two trials Rosenblatt et al. [5] evaluated SDF's preventive potential and concluded its preventive fraction to be 70.3%. However, the trials reported development of new lesions only in the teeth studied and not the entire dentition. Therefore, SDF's potential to prevent caries in the entire dentition is still questionable.

A meta-analysis by Oliveira et al. [37] evaluated the prevention of caries in deciduous dentition and concluded that SDF prevented caries development when compared with placebo or a fluoride varnish with a preventive fraction of 77.5%.

5.3. *Caries arrest in permanent dentition*

A pilot study on the arrest of incipient carious lesions in permanent molars [38] found SDF to be more effective than glass ionomer cement or toothbrushing at three and six month intervals. However, at thirty months, they were all found to be equally effective. Studies done by Llodra et al. and Liu et al. also concluded that SDF prevented occurrence of new lesions in permanent first molars [36,39]. None of the other systematic reviews however could draw conclusions regarding caries arrest in permanent dentition.

SDF has proved to be more effective in arresting caries in deciduous than permanent dentition. The mean number of new lesions for the SDF group was 0.29 in deciduous dentition and 0.37 for first permanent molars in the study done by Llodra et al. [36].

5.4. *Management of rampant caries*

Rampant caries is a very challenging dental disease to manage. Children with neglected oral hygiene, those suffering from severe systemic diseases are generally seen to have rampant caries. It affects multiple teeth that are ordinarily caries-free. Fluoride agents such as sodium fluoride (NaF) prevent caries, but are unable to halt progression of dental caries in dentine. SDF is a suitable option to halt the progression of rampant caries. It is non-invasive and therefore risk to spread infection is low and is readily accepted in younger children. It is an effective option for treating caries in children suffering from systemic diseases as well.

A young teenager suffering from major β-thalassemia with severe dentinal hypersensitivity was treated with three applications of SDF two weeks apart and followed up for four weeks. The child reported no dentinal hypersensitivity and carious lesions were arrested. Thus SDF not only arrested the progression of rampant caries but also treated dentinal hypersensitivity [40].

5.5. *Prevention of secondary caries*

Resistance of the cavity wall and margins to caries attack need to be increased in order to inhibit recurrence of secondary caries. This can be done with the use of SDF. Shimizu and Kawagoe in 1976 [41] found that after 26 months, the amalgam restorations of deciduous teeth that were pre-treated with SDF developed no recurrent caries. Mei et al. in 2016 evaluated SDF's effectiveness to prevent secondary caries under composite resin and glass ionomer cement restorations and observed reduction in secondary caries under the restorations following conditioning with SDF [42].

5.6. *Treatment of dentinal hypersensitivity*

SDF is approved to treat dentinal hypersensitivity, while its use for arresting carious lesions is off-label. A sequence of reactions takes place when it is applied to the teeth that blocks the dentinal tubules and promotes desensitization of the tooth. The silver ions from SDF result in precipitation of proteins in the dentinal tubules, while the fluoride reacts with calcium from the teeth forming calcium fluoride deposits that reduce the patency of the tubules. SDF when used with potassium iodide*(KI) generates silver iodide precipitate which further blocks the patency of the tubules. The net result of all this is reduction in dentinal hypersensitivity [43]. In a lesion like abrasion or erosion where dentinal hypersensitivity is precipitated by mechanical and thermal sensations, SDF application can be an effective alternative treatment [44].

5.7. *Treatment of Molar Incisor Hypomineralization (MIH)*

MIH is a challenging condition that can be observed in approximately 20–40 percent of first permanent molars. Such

teeth are extremely hypersensitive, difficult to anesthetise and are at a higher risk for rapid progression of caries. SDF can be successfully used to decrease sensitivity in such teeth and also arrest the progression of caries in them.

5.8. *Disinfection of the root canal system*

When used as 3.8% solution for irrigation of root canal, SDF has shown potent antimicrobial effect due to its inhibitory effects on synthesis of bacterial cell wall, DNA unwinding, and division of cell [45]. It can be used as a canal irrigant where black discolouration of dentine due to silver ions is not a problem. In 2012, Mathew et al. found that SDF is very effective in reducing bacterial load from canal wall and circumpulpal dentine [46].

5.9. *Pit and fissure sealant*

Morphologically, pits and fissures of teeth are more vulnerable to caries attack in comparison to smooth surfaces. Also access to these areas with a toothbrush is limited. Sato et al. [47], proved SDF's efficacy to prevent pit and fissure caries as a result of its antibacterial and remineralising property. A study done by Nishino and Massler [48], discovered that the caries score of the fissures treated with 8% stannous fluoride or silver nitrate was significantly higher than that treated with SDF. It can be used as an alternative to sealants in children who are unable to undergo a meticulous sealant procedure. However, the discolouration caused by SDF at these areas might be mistaken for an incipient lesion.

6. Effect of SDF on the restorative properties of different materials

SDF's compatibility with glass ionomer cements and composite resins grants it a valuable position in the paediatric dentist's inventory [49]. Numerous studies have proved that SDF does not alter or interfere with the bond strength of different restorative agents to dentine.

Quock et al. [50] evaluated the effect of SDF on the microtensile bond strength of resin composite to dentine. No significant change in the bond strength was seen between the SDF treated groups and the control groups. Changes in bond strength between self-etch and etch-and-rinse groups were also not significant. This concluded that the bond strength of composite resin to dentine is not altered with the application of SDF.

Zhao et al. [51] found that the application of KI solution immediately after SDF application did not hamper the shear bond strength of glass ionomer cements to dentine affected by caries.

A recent study in 2020 [52], compared the micro-tensile bond strength between resin modified glass ionomer cement and carious dentinal surfaces in deciduous teeth, with and without treatment with SDF and KI. In addition, SDF's effect on bond strength with and without acid-etching was also studied. The results showed that SDF and KI application with or without acid etching did not alter the bond strength between them.

Based on these results another approach for caries arrest; Silver Modified Atraumatic Restorative treatment (SMART) has been documented. In this technique SDF is applied and the tooth is restored immediately with glass ionomer cement. Placement of SDF and glass ionomer cement on the same appointment will help to restore the form and function of the tooth. It is especially useful when the patient will not be able to return for subsequent dental treatment.

7. Contraindications of SDF

- Individuals with an allergy to silver
- Individuals with ulcerations in oral cavity, especially the ones in close proximity to the area of SDF application.
- Tooth showing signs or symptoms of pulpal or periapical pathology.
- Failure to get consent to use SDF, and concerns regarding discolouration.

8. Clinical considerations for SDF application

Based on the results from various randomised controlled trials a reasonable protocol for SDF use might be as follows:

- 38% SDF to arrest and prevent caries is effective in both deciduous and permanent dentitions.
- Biannual application of 38% SDF is recommended.
- Parents and children have to be informed regarding the discolouration caused by SDF application.
- A detailed informed consent to fully convey the benefits and limitations of this therapy is recommended.
- No aerosol generated during its application.
- No caries excavation is necessary. However, surfaces clean of food debris are desirable to allow direct contact of the solution with dentine.
- One minute application with air-drying as per the manufacturer's recommendations is consistent with the best results for caries arrest.
- Caries arrest in large cavities and posterior teeth may be less with only a single application.
- A one-month follow-up in order to evaluate the arrest and further need for re-application on active treated carious surfaces should be advantageous.

9. Safety of SDF

One of the primary concerns with SDF application is the amount of fluoride dose. A single drop of SDF, has 2.24 mg F/dose which is adequate to treat six teeth. Therefore application of 1 SDF drop will result in a lesser quantity of fluoride than that present in 0.25 mL of fluoride varnish.

No adverse systemic effects due to SDF have been noted, although the long-term effects due to repeated silver exposure is unknown [9,53]. However, a total of 1g of silver exposure would be required for the cumulative effect and risk of silver

poisoning to take place. This would correspond to approximately 400 applications of SDF as per the U.S. Environmental Protection Agency [54].

Acute side effects of the SDF on either children or adults has not been reported. Minor side effects may include metallic taste, soft tissue irritation, small reversible white lesions on the mucosa, and gingivitis [6,55]. A randomised control trial conducted by Milgrom et al. evaluated the adverse effects of application of SDF within 24–48 h by a questionnaire based survey. The questions included were visit to the emergency care; experiencing nausea, vomiting, difficulty in breathing and swallowing; swelling surrounding the lips and rashes. The majority of the adverse effects reported were either mild diarrhoea or stomach ache that all resolved within 48 h of reporting. One child reported to have a non-irritated, non-sore, spot at the corner of the mouth which occurs typically due to silver precipitation on contact with the skin. It resolved within 2 weeks. No tooth pain was reported, despite some lesions being deep. No mucosal or gingival irritation was observed during follow-up [56].

Another study done with an aim to check for gingival erythema following SDF application found that though some participants showed mild erythema at day 1, there was no change at day 7 from baseline [57]. This suggested that mild irritations of gingiva heal within a few days.

10. Drawbacks of SDF

Black discoloration of the carious lesion following application of SDF is the main side effect and has raised major concerns regarding parental satisfaction. A study done in 2018 [58], reported that, inspite of the discolouration caused by SDF, parental satisfaction with their child's dental appearance ranged between 71 and 62% after a period of thirty months. A survey in USA used photographs of pre and post treatment with SDF and found that the parents relatively accepted staining on posterior teeth compared to anterior teeth. Nevertheless, even those parents who found staining on anterior teeth disagreeable, accepted SDF treatment in order to avoid other behavioural techniques like sedation and general anaesthesia [59].

Various attempts have been undertaken in the past to resolve this issue. Use of ammonium hexafluorosilicate and zinc fluoride have been tried earlier but these failed to inhibit dentine collagen degradation and demineralization to a greater extent when compared with SDF [60,61]. Knight et al. [49] reported that application of KI reduced SDF associated tooth discoloration. The iodide ions reacted with the excess silver ions resulting in the formation of a yellowish silver iodide precipitate that minimized the discolouration. However, the application of KI failed to have a long-lasting effect on improving the blackish discolouration that caused aesthetic concerns [62].

Sayed et al. in 2018, found that glutathione biomolecule also reduces SDF associated tooth discoloration, particularly on enamel and to a lesser degree on dentine [63]. Recently silver nanoparticles are being tested to resolve this discolouration problem. A study found no discolouration of the treated caries lesion with the use of nano silver fluoride [64].

Apart from the discolouration, it should be noted that SDF does not eradicate dental caries but, arrests its progression on the treated surfaces and might aid in remineralisation. It doesn't restore the tooth structure and function. So, a significant breakdown of the tooth, might deteriorate the occlusion and long-term clinical outcome if proper form and function of the treated tooth is not restored [65].

Also, SDF should be handled with care as it can temporarily stain gingiva and skin.

11. Scope for improvement

Though SDF's efficacy to arrest caries is well established, concerns regarding the frequency and timing of application still need to be addressed. The consistency and longevity of caries arrest with SDF is still unknown. Additional studies are required to prove its effectiveness on permanent dentition and its efficacy and safety as a canal irrigant and intracanal medicament. Currently no literature analyzes SDF's effect with regards to exposure of pulp and its application as a direct pulp capping agent. Furthermore research regarding the integration of the product into restorative protocols to minimise discolouration associated with it need to be done.

12. Conclusion

SDF is an effective, sustainable and inexpensive option to treat children and adolescents with high caries risk for caries arrest. For individuals who are unable to endure conventional restorative treatment modalities, who cannot access proper dental care facilities, and those with special health-care needs, it is an effective alternative option. But having said that, SDF is not a magic medication for the management of a carious lesion. Careful selection of cases, tooth location, lesion size and location, presence of plaque and other dietary habits play an equally important role for it to be effective. A comprehensive treatment plan evaluating and controlling all the individual risk factors is necessary for treatment with SDF to be successful and caries arrest to occur.

Funding source

Nil.

Conflicts of interest

There are no conflicts of interest.

Acknowledgements

I would like to thank my contributing authors and the Department of Paediatric and Preventive Dentistry at JSS Dental College, Mysuru. This article is the net result of all our hard work that was well guided by my guide and professors.

REFERENCES

[1] Selwitz RH, Ismail AI, Pitts NB. Dental caries. Lancet 2007;369:51–9.
[2] Chu CH, Mei ML, Lo EC. Use of fluorides in dental caries management. Gen Dent 2010;58(1):37–43. quiz 44–35, 79–80.
[3] Rose TP. Sterilization of carious dentine with silver nitrate. Chronicle 1976;39:151–9.
[4] Langeland K, Langeland LK. Indirect capping and the treatment of deep carious lesions. Int Dent J 1968;18:326–80.
[5] Rosenblatt A, Stamford T, Niederman R. Silver diamine fluoride: a caries "silver-fluoride bullet". J Dent Res 2009;88:116–25.
[6] Nishino M, Yoshida S, Sobue S, Kato J, Nishida M. Effect of topically applied ammoniacal silver fluoride on dental caries in children. J Osaka Univ Dent Sch 1969;9:149–55.
[7] Yamaga R, Nishino M, Yoshida S, Yokomizo I. Diamine silver fluoride and its clinical application. J Osaka Unic Dent Sch 1972;12(20):1–10.
[8] Chu CH, Lo ECM, Lin HC. Effectiveness of silver diamine fluoride and sodium fluoride varnish in arresting dentin caries in Chinese pre-school children. J Dent Res 2002;81(11):767–70.
[9] Crystal YO, Marghalani AA, Ureles SD, Wright JT, Sulyanto R, Divaris K, et al. Use of silver diamine fluoride for dental caries management in children and adolescents, including those with special health care needs. Pediatr Dent 2017;39(5):135–45.
[10] Mei ML, Lo ECM, Chu CH. Arresting dentine caries with silver diamine fluoride: what's behind it? J Dent Res 2018;97(7):751–8.
[11] Marx DE, Barillo DJ. Silver in medicine: the basic science. Burns 2014;40(Suppl 1):S9–18.
[12] Slawson RM, Lee H, Trevors JT. Bacterial interactions with silver. Biol Met 1990;3(3–4):151–4.
[13] Russell AD, Hugo WB. Anti-microbiological activity and action of silver. Prog Med Chem 1994;31:351–70.
[14] Wu MY, Suryanarayanan K, van Ooij WJ, Oerther DB. Using microbial genomics to evaluate the effectiveness of silver to prevent biofilm formation. Water Sci Technol 2007;55:413–9.
[15] Knight G, McIntyre J, Craig G, Mulyani, Zilm P, Gully N. An in vitro model to measure the effect of a silver fluoride and potassium iodide treatment on the permeability of demineralized dentine to Streptococcus mutans. Aust Dent J 2005;50:242–5.
[16] Mei ML, Li QL, Chu CH, Lo ECM, Samaranayake LP. Antibacterial effects of silver diamine fluoride on multi-species cariogenic biofilm on caries. Ann Clin Microbiol Antimicrob 2013;12:4.
[17] Chen W, Liu Y, Courtney HS, Bettenga M, Agrawal CM, Bumgardner JD, et al. In vitro anti-bacterial and biological properties of magne-tron co-sputtered silver-containing hydroxyapatite coating. Biomaterials 2006;27(32):5512–7.
[18] Koo H. Strategies to enhance the biological effects of fluoride on dental biofilms. Adv Dent Res 2008;20(1):17–21.
[19] Suzuki T, Nishida M, Sobue S, Moriwaki Y. Effects of diammine silver fluoride on tooth enamel. J Osaka Univ Dent Sch 1974;14:61–72.
[20] Lou YL, Botelho MG, Darvell BW. Reaction of silver diamine fluoride with hydroxyapatite and protein. J Dent 2011;39(9):612–8.
[21] Ten Cate JM. Contemporary perspective on the use of fluoride products in caries prevention. Br Dent J 2013;214(4):161–7.
[22] Ogard B, Seppä L, Rølla G. Professional topical fluoride applications— clinical efficacy and mechanism of action. Adv Dent Res 1994;8(2):190–201.
[23] Okazaki M, Miake Y, Tohda H, Yanagisawa T, Matsumoto T, Takahashi J. Functionally graded fluoridated apatites. Biomaterials 1999;20(15):1421–6.
[24] Mei ML, Nudelman F, Marzec B, Walker JM, Lo ECM, Walls AW, et al. Formation of fluorohydroxyapatite with silver diamine fluoride. J Dent Res 2017;96(10):1122–8.
[25] Angker L, Nijhof N, Swain MV, Kilpatrick NM. Influence of hydration and mechanical characterization of carious primary dentine using an ultra-micro indentation system (UMIS). Eur J Oral Sci 2004;112:231–6.
[26] Chu CH, Lo ECM. Microhardness of dentine in primary teeth after topical fluoride applications. J Dent 2008;36(6):387–91.
[27] Mei ML, Ito L, Cao Y, Li QL, Chu CH, Lo EC. The inhibitory effects of silver diamine fluorides on cysteine cathepsins. J Dent 2014;42(3):329–35.
[28] Mei ML, Li QL, Chu CH, Yiu CK, Lo EC. The inhibitory effects of silver diamine fluoride at different concentrations on matrix metalloproteinases. Dent Mater 2012;28(8):903–8.
[29] Crystal YO, Niederman R. Silver diamine fluoride treatment considerations in children's caries management. Pediatr Dent 2016;38(7):466–71.
[30] Gao SS, Zhao IS, Hiraishi N, Duangthip D, Mei ML, Lo ECM, et al. Clinical trials of silver diamine fluoride in arresting caries among children: a systematic review. JDR Clin Transl Res 2016;1(3):201–10.
[31] Fung MHT, Duangthip D, Wong MCM, Lo ECM, Chu CH. Randomized clinical trial of 12% and 38% silver diamine fluoride treatment. J Dent Res 2018;97(2):171–8.
[32] Duangthip D, Wong MCM, Chu CH, Lo ECM. Caries arrest by topical fluorides in pre-school children: 30-month results. J Dent 2018;70:74–9.
[33] Mabangkhru S, Duangthip D, Chu CH, Phonghanyudh A, Jirarattanasopha V. A randomized clinical trial to arrest dentin caries in young children using silver diamine fluoride. J Dent [Internet] 2020;(April):103375.
[34] Gao SS, Zhang S, Mei ML, Lo ECM, Chu CH. Caries remineralisation and arresting effect in children by professionally applied fluoride treatment - a systematic review. BMC Oral Health [Internet] 2016;16(1):1–9. https://doi.org/10.1186/s12903-016-0171-6. Available from:.
[35] Zhi QH, Lo EC, Lin HC. Randomized clinical trial on effectiveness of silver diamine fluoride and glass ionomer in arresting dentine caries in preschool children. J Dent 2012;40(11):962–7.
[36] Llodra JC, Rodriguez A, Ferrer B, Menardia V, Ramos T, Morato M. Efficacy of silver diamine fluoride for caries reduction in primary teeth and first permanent molars of schoolchildren: 36-month clinical trial. J Dent Res 2005;84(8):721–4.
[37] Oliveira BRA, Veitz-Keenan A, Niederman R. The effect of silver diamine fluoride in preventing caries in the primary dentition: a systematic review and meta-analysis. Caries Res 2018;53(1):24–32.
[38] Braga MM, Mendes FM, De Benedetto MS, Imparato JCP. Effect of silver diamine fluoride on incipient caries lesions in erupting permanent first molars: a pilot study. J Dent Child 2009;76(1):28–33.
[39] Liu BY, Lo EC, Chu CH, Lin HC. Randomized trial on fluorides and sealants for fissure caries prevention. J Dent Res 2012;91(8):753–8.
[40] Chu CH, Lee AHC, Zheng L, Mei ML, Chan GCF. Arresting rampant dental caries with silver diamine fluoride in a young teenager suffering from chronic oral graft versus host disease post-bone marrow transplantation: a case report. BMC Res Notes 2014;7(1).
[41] Shimizu A, Kawagoe M. A clinical study of diamine silver fluoride on recurrent caries. J Osaka Univ Dent Sch 1976;16:103–9.

[42] Mei ML, Zhao IS, Ito L, Lo ECM, Chu CH. Prevention of secondary caries by silver diamine fluoride. Int Dent J 2016;66(2):71–7.
[43] Seifo N, Robertson M, MacLean J, Blain K, Grosse S, Milne R, et al. The use of silver diamine fluoride (SDF) in dental practice. Br Dent J 2020;228(2):75–81.
[44] Kimura K, Iso Y, Ohno M. Clinical test of diammine silver fluoride (saforide) applied to hypersensitive dentin. Shikagakuho 1971;71:708–13.
[45] Okamoto E, Kutsuna H, Nakamura Y. Effect of diamine silver fluoride on treatment of infected root canal part 1. On the number of treatments required for root canal filling. Nippon Dent Rev 1971;343:625–6.
[46] Mathew VB, Madhusudhana K, Sivakumar N, Venugopal T, Reddy RK. Anti-microbial efficiency of silver diamine fluoride as an endodontic medicament – an *ex vivo* study. Contemp Clin Dent 2012;3:262–4.
[47] Sato R, Sailo Y. Clinical application of silver ammonia fluoride (saforide) to children. Nippon Dent Rev 1970;332:66–7.
[48] Nishino M, Massler M. Immunization of caries-susceptible pits and fissures with a diammine silver fluoride solution. Jpn J Pedod 1972;10:6–11.
[49] Knight GM, McIntyre JM. The effect of silver fluoride and potassium iodide on the bond strength of autocure glass ionomer cement to dentine. Aust Dent J 2006;51(1):42–5.
[50] Quock R, Barros J, Yang S, Patel S. Effect of silver diamine fluoride on microtensile bond strength to dentin. Operat Dent 2012;37(6):610–6.
[51] Zhao IS, Chu S, Yu OY, Mei ML, Chu CH, Lo ECM. Effect of silver diamine fluoride and potassium iodide on shear bond strength of glass ionomer cements to caries-affected dentine. Int Dent J 2019:1–7.
[52] Uchil SR, Suprabha BS, Suman E, Shenoy R, Natarajan S, Rao A. Effect of three silver diamine fluoride application protocols on the microtensile bond strength of resin-modified glass ionomer cement to carious dentin in primary teeth. J Indian Soc Pedod Prev Dent 2020;38:138–44.
[53] Burgess JO, Vaghela PM. Silver diamine fluoride: a successful anticarious solution with limits. Adv Dent Res 2018;29(1):131–4.
[54] Vasquez E, Zegarra G, Chirinos E, Castillo JL, Taves DR, Watson GE, et al. Short term serum pharmacokinetics of diammine silver fluoride after oral application. BMC Oral Health 2012;12:60.
[55] Mei ML, Lo EC, Chu CH. Clinical use of silver diamine fluoride in dental treatment. Comp Cont Educ Dent 2016;37(2):93–8.
[56] Milgrom P, Horst JA, Ludwig S, Rothen M, Chaffee BW, Lyalina S, et al. Topical silver diamine fluoride for dental caries arrest in preschool children: a randomized controlled trial and microbiological analysis of caries associated microbes and resistance gene expression. J Dent [Internet] 2018;68:72–8. https://doi.org/10.1016/j.jdent.2017.08.015. Available from:.
[57] Castillo JL, Rivera S, Aparicio T, Lazo R, Aw T-C, Mancl LL, et al. The short-term effects of diamine silver fluoride on tooth sensitivity: a randomized controlled trial. J Dent Res 2011;90(2):203–8.
[58] Duangthip D, Fung MHT, Wong MCM, Chu CH, Lo ECM. Adverse effects of silver diamine fluoride treatment among preschool children. J Dent Res 2018;97(4):395–401.
[59] Crystal YO, Janal MN, Hamilton DS, Niederman R. Parental perceptions and acceptance of silver diamine fluoride (SDF) staining. J Am Dent Assoc 2017;148(7):510–8. e4.
[60] Kawasaki A, Suge T, Ishikawa K, Ozaki K, Matsuo T, Ebisu S. Ammonium hexafluorosilicate increased acid resistance of bovine enamel and dentine. J Mater Sci Mater Med 2005;16(5):461–6.
[61] Thanatvarakorn O, Islam MS, Nakashima S, Sadr A, Nikaido T, Tagami J. Effects of zinc fluoride on inhibiting dentin demineralization and collagen degradation in vitro: a comparison of various topical fluoride agents. Dent Mater J 2016;35(5):769–75.
[62] Li R, Lo EC, Liu BY, Wong MC, Chu CH. Randomized clinical trial on arresting dental root caries through silver diammine fluoride applications in community-dwelling elders. J Dent 2016;51:15–20.
[63] Sayed M, Matsui N, Hiraishi N, Nikaido T, Burrow MF, Tagami J. Effect of glutathione bio-molecule on tooth discoloration associated with silver diammine fluoride. Int J Mol Sci 2018;19(5):E1322.
[64] Tirupathi S, Svsg N, Rajasekhar S, Nuvvula S. Comparative cariostatic efficacy of a novel Nano-silver fluoride varnish with 38% silver diamine fluoride varnish a double-blind randomized clinical trial. J Clin Exp Dent 2019;11(2):e105–12.
[65] McConnachie I, Friedman CS, Abrams SA. Silver diamine uoride: a new tool against caries or a game changer? J Ontario Dent Assoc 2018;95:36–40.